The role of lexical tone in spoken word recognition of Chinese

by

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Abstract

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The present study used a direct priming task in order to investigate the nature and processing of tonal information in spoken word recognition of Chinese. Two experiments were conducted. In Experiment 1, prime-target pairs contrasted in terms of tonal and segmental overlap. Experiment 1 replicated the first experiment of C.-Y. Lee's (2007) study but with a significant modification that balanced tonal information in prime-target pairs. Forty-eight monosyllabic Mandarin target words were paired with four types of primes in which prime and target were identical (*e.g., bo1– bo1*), shared only segmental information (*e.g., bo1 –bo2*), shared only tonal information (*e.g., bo1 –zhua1*) or were unrelated (*e.g., bo1 –man3*). Experiment 2 extended the prime-target paradigm to include minimal segmental overlap in onset and in offset portion. Forty-eight monosyllabic Mandarin target words were paired with four types of primes in which prime and target were identical (*e.g., bo1– bo1*), shared tonal and only onset segmental

information (*e.g., bo1 –bin1*), shared tonal and only offset segmental information (*e.g., bo1 –po1*) or were unrelated (*e.g., bo1 –man3*).

The results of Experiment 1 showed that the facilitation effect was found when the prime-target pairs were identical or segmental structure overlapped compared to conditions where the prime-target pairs only overlapped in tone or were unrelated. Effects of similarity of tone across prime-target segmental pairs were also analyzed. The results of Experiment 2 showed that the facilitation effect was only found when the prime-target pairs were identical. Partial segmental overlap in conjunction with tone resulted in inhibition compared to an unrelated control.

Together, these data indicate that segmental information can facilitate word recognition, with segmental information carrying more weight than tonal information in the processing of spoken Chinese.

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Introduction

The process of spoken word recognition is an important issue in language comprehension. It is not a simple task due to many sources of variability including prosodic factors such as stress, intonation and rate, which can also influence the overall meaning of a word. For example, a given word can have a completely different meaning by changing its stress or intonation pattern. Moreover, there are no clear boundaries in continuous speech. In comprehension, a listener needs to know where a word starts and ends and must use acoustic and contextual information to identify the word. During speech processing, semantic and syntactic constraints are naturally integrated with incoming speech. The interactive nature of the perceptual process is a key point in the investigation of spoken word recognition.

The world's languages can be divided into two categories on the basis of whether they have lexical tone. Non-tonal languages include languages such as English, Dutch and French. In these non-tonal languages, lexical stress often plays an important role. In many lexical stress languages, stress position in the word is fixed; therefore, stress is not lexically distinctive. However, some stress languages use the stress pattern to distinguish word meanings. For example, two English words can have the same segmental structure but different word meaning on the basis of different stress pattern (e.g., *FORbear* and *forBEAR*; upper case indicates stress). However, in English, only a few English words are distinguished by their stress pattern.

Tonal languages include languages like Chinese and Thai. In tonal languages, tones contain lexical information and tones are used to distinguish word meanings. Consider Mandarin Chinese for example.

Tones in Mandarin

There are four tones in Mandarin Chinese differing in pitch and duration. They are high-level (Tone 1), mid-rising (Tone 2), low-dipping (Tone 3) and high-falling (Tone 4). Each syllable can combine with each of the four tones, which will change meaning. For example, the syllable *ma* could mean mother (first tone), hemp (second tone), horse (third tone) and scold (fourth tone). The fundamental frequency, F0, contours for each of the four Mandarin tones for the segmental context *ma* are shown in **Figure 1**. Words with the same segmental phonetic content but differing in tone can express different meanings. Therefore, there are more homophonic words in Chinese than in many other languages. It is clear that lexical tone plays an important role in distinguishing word meaning just like segmental structure.

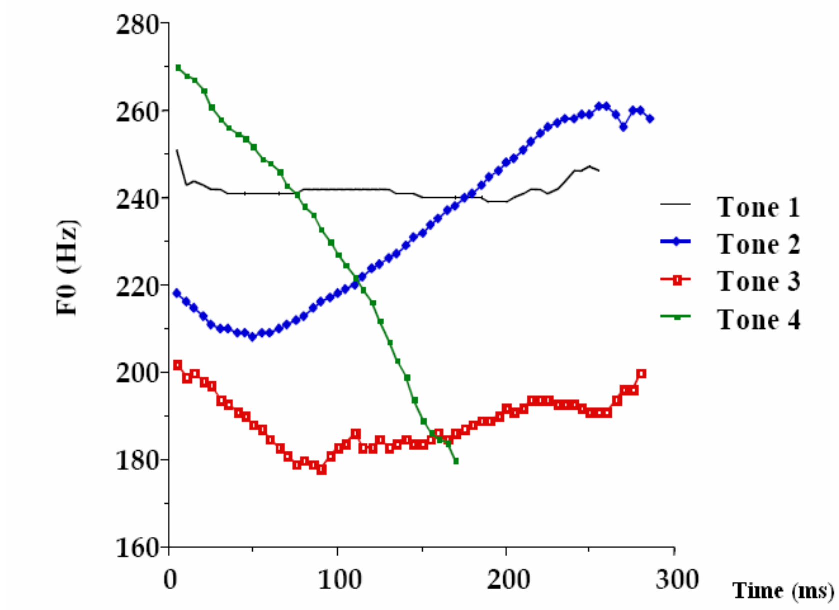

Figure 1. F_0 contours for the four Mandarin tones, each combined with the syllable *ma* produced by a female native speaker (from Moore and Jongman, 1997).

Hemispheric Difference

Some studies have attempted to establish hemispheric specialization for tonal processing in claiming an important role for tone. For example, Van Lancker and Fromkin (1973) used a dichotic-listening task to examine native speakers of a tonal language, Thai, and a non-tonal language, English. Three sets of stimuli were used to compare ear preference. The first set was tone-words in which words were only different in tone. The second set was consonant-words in which words were only different in initial consonant. The third set was hums in which the stimuli had no segmental information. The authors found that Thai speakers showed a significant right ear advantage (REA), a left hemisphere advantage, for the tone-words and consonant-words but not for the hummed stimuli. On the contrary, English speakers only showed a REA for the consonant-words. Van Lancker and Fromkin interpreted the results by hypothesizing that Thai speakers processed the tone-words and consonant-words as language, while the hums were considered as non-linguistic stimuli. For English speakers, the REA was only found for the consonant-words. Since English is not a tonal language, English listeners did not process the tone-words and hums as language. These tone-words and hums were not lateralized in the left hemisphere by English listeners. Van Lancker and Fromkin suggested that a left-hemisphere specialization occurred when pitch differences functioned linguistically for the listeners.

Wang, Jongman and Sereno (2001) used a dichotic-listening task to examine Mandarin tones by native speakers of Chinese and native speakers of American English. Sixteen monosyllabic Mandarin words, in which four different syllables, combined with four different tones, were used as the stimuli. The native speakers of American English were trained before the experiment in order to be familiar with Mandarin tones. The results showed that the Chinese listeners made more errors in the left ear, which suggested that there was a REA, a left hemisphere advantage, for the Chinese listeners. However, the American listeners made equivalent errors for right and left ears, which indicated no ear preference for the American listeners. The results suggested that the native speakers of Mandarin processed Mandarin tones in the left hemisphere, but the native speakers of American English processed Mandarin tones bilaterally. This study demonstrated that the left hemisphere predominates for Mandarin tone processing, similar to language processing in other tonal languages.

Wang, Behne, Jongman, and Sereno (2004) used a dichotic listening task to investigate whether linguistic experience influences the hemispheric processing of lexical tone. Wang et al. (2004) found that native Mandarin listeners and English-Mandarin bilinguals had equivalent performance of identifying Mandarin tones in dichotic listening tasks, while native speakers of American and Norwegian showed no hemispheric lateralization even though the Norwegian listeners were familiar with Norwegian tones. It demonstrated that different linguistic experience affected the hemispheric processing of lexical tone in spite of the familiarity with lexical tone in their first language.

Gandour (1988) examined the extent and nature of the impairment in the perception and production of tones in aphasia. Eight brain-damaged patients of Thai including six aphasic patients and two nonaphasic patients participated in the experiment. Five monosyllabic Thai words, which were minimally different in tone (Thai contrasts five tones), were used in the experiment. The subjects were asked to read the word shown on the cards. The sounds were recorded separately and were presented and judged by native speakers of Thai. The results showed that the left-brain damaged patients had a tone production deficiency when comparing with the normal and right-brain damaged subjects. It indicated that the performance of left-brain damaged aphasic patients significantly differed from normal subjects, but the right-brain damaged aphasic patients did not.

The above studies demonstrate that tonal information is processed in the left hemisphere by native speakers of tonal languages, which suggests tonal information is used linguistically to differentiate lexical identity.

Tonal word recognition

Several studies have examined the role of segmental and suprasegmental information in word recognition. For example, Soto-Faraco, Sebastian-Galles and

Cutler (2001) investigated word recognition in Spanish. In the study, Spanish words differing in suprasegmental information (e.g., *saBAna* “savannah” – *SAbana* “sheet”; upper case indicates stress) were used as the stimuli in cross-modal fragment priming experiments. In the experiment, the auditory primes, two first syllables of a word, were used as word fragments and presented at the end of a sentence. The visual targets had the same stress pattern and segmental structure as the prime (e.g., *PRINci-* [from the word *PRINcipe* “prince”]-*PRINcipe* “prince”) or differed from the auditory primes in either stress pattern (e.g, *prinCI-* [from the word *prinCIpio* “beginning”]-*PRINcipe* “prince”) or segmental structure differing in one vowel or one consonant (e.g., *abun-* [from the word *abunDaNcia* “abundance”]-*abanDOno* “abandonment”). The results showed that priming occurred when the prime and the target fully matched in stress pattern and segmental structure, while a comparable inhibition effect was found when the prime and target mismatched either suprasegmentally or segmentally. The results also indicated the matching and mismatching candidates were initially activated; the inhibition effect, which was found in mismatching primes, occurred because the listeners needed to wait until the mismatching vowel or consonant provided enough information. The authors suggested that both suprasegmental and segmental information influenced the activation of word recognition in the same way.

Schirmer, Tang, Penney, Gunter and Chen (2005) used the event-related potential (ERP) to examine the time course of the role of tone and segmental information in speech processing. In the study, the stimuli were 60 three-clause sentences in which a target was located at the end of the second sentence. Four types of monosyllabic Cantonese words, which were semantically correct, tone mismatch, segmental mismatch or unrelated, were used as target words. The subjects were asked to identify whether the sentences they heard were semantically correct or incorrect. The results showed that mismatched targets in the sentence caused a larger negativity in the ERP than congruous target words. Based on the ERPs, the authors concluded that the listeners processed tone information and segmental information at a similar time in the processing of Cantonese words, which was in line with the finding reported by Soto-Faraco et al. (2001).

Fox and Unkefer (1985) used a tone identification task to investigate lexical effects in processing of tonal information of Mandarin Chinese. Eleven Chinese and 11 American subjects participated in the experiment. In the study, four different tone 1-tone 2 pairs, which had the same vowel [ei] but with a different initial consonant, were used as the stimuli. Four possible combinations of word-nonword orderings were created which were word-word, word-nonword, nonword-word and nonword-nonword. The subjects were asked to determine whether the stimuli were a tone 1 or tone 2 by circling a “1” or “2” on the answer sheet. The results showed that the Chinese subjects had a shift in tone boundary toward nonwords in the word/nonword and nonword/word continua relative to the word/word continuum, but no shift was found for the American subjects. That is, the Chinese subjects had more word responses than nonword responses to word/nonword and nonword/word pairs. The tone category identification was biased toward forming a word response. These data indicated that lexical information could influence the perception of tone.

Repp and Lin (1990) used a speeded classification paradigm to examine the combination of segmental structure and tone information in speech. In the study, three Mandarin CV syllables, combined with tone 1 and tone 2, produced six words and six nonwords. These 12 syllables were manipulated in three conditions by varying tonal and segmental dimensions in which one dimension was varied and another one was held constant (control), both dimensions were varied but one dimension accompanied one value of the other dimension (correlated), or both dimensions were varied but each quality of one dimension accompanied each quality of the other dimension (orthogonal). Four classification tasks combining with different tonal and segmental dimensions, which were consonant/tone, vowel/tone, tone/consonant and tone/vowel, were investigated in the experiment. The subjects were asked to identify the syllable by pressing the appropriate key. The results showed that in the tone/consonant task, the Mandarin subjects had a longer reaction time for making tonal decisions than for making segmental decisions. This indicated that the Mandarin subjects had more confusion from irrelevant Mandarin consonants than for non- Mandarin tones. In addition, Mandarin subjects had shorter reaction times in making tonal discriminations than English subjects relative to their reaction time for making segmental discriminations. The results of tone/vowel and vowel/tone tasks showed that the English subjects had a consistent performance, while the Mandarin subjects performed inconsistently. The authors suggested that a vowel with different tones might appear to be a different vowel for the listeners, while a tone on a different vowel was still considered as the same tone. Therefore, linguistic experience might influence the perceptual processing of the English and the Mandarin subjects, which was in line with the findings of Wang et al. (2004).

More recently, Lee, Vakoch and Wurm (1996) examined the role of linguistic experience in tone perception by native speakers of Cantonese, Mandarin and English. In the first experiment, seventy-eight subjects including 27 Cantonese, 21 Taiwanese, and 30 Americans participated. Fifty-four Cantonese tone pairs including the six distinctive lexical tones in Cantonese were used as the stimuli. Eighteen tone pairs had the same phoneme and tone. The other 36 tone pairs had the same phoneme but different tones. In addition, 18 of the 36 tone pairs were word/word pairs, and the other 18 tone pairs were word/nonword pairs. The subjects were asked to identify whether the two tones they heard were the same or different. The results showed that the Cantonese group performed better than the Mandarin and English groups, and there was no obvious difference between the Mandarin and English groups. In addition, the Cantonese group had better performance on words than nonwords; however, this result was not found in the Mandarin and English groups. This indicated that the Cantonese subjects were more familiar with the Cantonese tones than non-Cantonese tones. In the second experiment, 68 subjects including 23 native Cantonese speakers, 20 native Mandarin speakers and 25 native English speakers participated. The procedure and stimuli design were the same as those in the first experiment except that the Cantonese words and nonwords were changed to Mandarin words and nonwords. The results showed that the Mandarin group had the best performance and the Cantonese group performed better than the English group at discriminating Mandarin tones. The Cantonese group had the better performance than the English group at discriminating Mandarin tones but it was not found for the Mandarin group when discriminating Cantonese tones. It might be easier for the native Cantonese speakers to differentiate Mandarin tones because Mandarin has fewer tones than Cantonese. The findings of the two experiments suggested that tone perception was affected by the listeners' linguistic background, and that native speakers of tonal languages were better at distinguishing tones from their own language than from other tonal languages and better than speakers from non -tonal languages.

Since native speakers of tonal languages and non-tonal languages process the tonal information differently, many questions emerge regarding the role of tonal information in word recognition in tonal languages. Taft and Chen (1992) used homophonic decision tasks to investigate the sensitivity of tone information in Mandarin. The subjects were divided into two groups. In the aloud group but not in the silent group, the subjects were asked to read the characters aloud before making their responses. In Experiment 1, Mandarin homophonic pairs (e.g., ‘保’,’飽’, both pronounced *bao3*) and non-homophonic pairs (e.g., ‘曲’,’去’, pronounced *qi3*, *qi4*, respectively), which were created by two items differing only in tone, vowel or both, were used as the stimuli. The results showed that the subjects responded more slowly to mismatches in tone whether the subjects read aloud before making decisions or not. In Experiment 2, the stimuli were Cantonese homophonic pairs and non-homophonic pairs in which two items differed only in tone, vowel, consonant or neither used in Experiment 1 except for changing from Mandarin pairs to Cantonese pairs. The results were consistent with the findings of Experiment 1 showing that tone information was not processed in the first phase in the processing of Mandarin and Cantonese syllables. However, the error rate of Cantonese subjects was lower than that of the Mandarin subjects. The pattern of data might result from the diversity of structure of Cantonese and Mandarin. Because Cantonese has more tones than Mandarin, it has fewer homophones. In Experiment 3, Mandarin homophones and non-homophones were used as the stimuli. The stimuli contained two types of condition, which were competing tone (same segmental structure but different tone) and no competing tone (no other syllable pronounced with the same segmental structure). The results of the non-homophone group showed that the subjects responded slower to competing tones than non-competing tones, while the results of the homophone group showed a reversal. The authors suggested that the tonal information was not activated in the first phase, and syllables with the same segmental structure but different tone were more easily accepted as homophones. Overall, tonal information showed a disadvantage in the processing of Mandarin and Cantonese isolated words.

Cutler and Chen (1997) used a lexical decision task and a same-different task to investigate the processing of tonal and segmental information of Cantonese syllables. In a lexical decision task, 12 sets of eight disyllabic items in which each set of items used one disyllabic word (e.g., /bok8-si6/ "doctor"; number indicates Cantonese tones) to create seven disyllabic nonwords were used as the stimuli. The seven disyllabic nonwords differed by onset, vowel or tone from the original disyllabic words (e.g., */bok8 – si2/* tone mismatch; */bok8 - sy6/* vowel mismatch; */bok8 - sy2/* vowel-tone mismatch; */bok8 - ji6/* onset mismatch; */bok8 - ji2/* onset-tone mismatch; */bok8 - jy6/* onset-vowel mismatch; */bok8 - jy2/* onset-vowel-tone mismatch). The results showed that the subjects had more errors when nonwords and words only differed in tone. That is, the subjects were more likely to accept the nonwords as real words when the disyllabic items were only tone- mismatches. Additionally, the error rate for vowel difference alone was lower than for the tone difference alone. In a same-different task, two sets of eight words and eight nonwords were used as the stimuli. Each set of words or nonwords was formed by using two onsets, two vowel rhymes and two tones, and then created eight possible pairs. The subjects were asked to determine whether the two syllables in the pair were the same or different by pressing a key. The results were similar to the results of the lexical decision task. When the subjects heard a pair of syllables differing in tone, they had slower responses and more errors than other combinations, which was in line with the data reported by Taft & Chen (1992). The authors suggested that tonal information was not processed until the vowel information was available because the tonal information often applies later than the vowel information that bears the tone.

Chen and Cutler (1997) also examined the process of spoken word recognition in Cantonese. In the study, target words were paired with three types of primes, which were unrelated, semantically related or phonologically related. In addition, the phonologically related prime had the same beginning or the same ending syllable as the target but differed in tone or in rhyme. In the auditory lexical decision task, the facilitation effect was found in the phonological related condition in which the prime and the target shared the same end and in the semantic related condition. When the prime and target shared the end, it facilitated the recognition process, which was consistent with the results of Radeau et al. (1995). However, when the prime and target had the same beginning, it slowed recognition.

Zhou (2000) investigated phonological processing in reading Chinese compound words by using visual-visual and auditory-visual priming lexical decision tasks. Chinese compound words, which shared segmental patterns but differed in lexical tones with high and low frequency conditions, were used as the stimuli. In addition, unrelated compound words and phonological related word-nonword pairs differing in tone were used as the stimuli. The results showed that no priming effect was found in the visual-visual priming, while in the auditory-visual priming, an inhibition effect was found when the prime and the target were phonologically related, which was consistent with the findings of Taft & Chen (1992) and Cutler & Chen (1997). Moreover, a larger inhibition effect was found when low frequency targets were preceded by high frequency primes in visual-visual priming. Zhou concluded that the phonological information was an automatical activation, which affected the processing of semantic information in reading Chinese.

Yip, Leung, and Chen (1998) used a forward and backward shadowing task to examine the processing of tonal and segmental structure in Cantonese. In the forward priming task, the target of shadowing was the second syllable of each trial, while in the backward shadowing task the target was the first syllable. Forty sets of five monosyllabic Cantonese words were used as the stimuli. The prime and target differed in onset, rhyme, tone or all (e.g., *do2-cho2* onset mismatch; *chi2-cho2* rhyme mismatch; *gwa1-cho2* unrelated). The results showed that the facilitation effect was only found when the prime and target differed in tone in the forward shadowing task. The authors suggested that the priming effect was found in the forward shadowing task because the subjects were more inefficient in using stored tonal information than in using stored segmental information in the processing of spoken words. However, no facilitation but rather an inhibition effect was found in phonologically related conditions in the backward shadowing task, which was consistent with the findings of Taft & Chen (1992), Cutler & Chen (1997) and Zhou (2000) showing a tone disadvantage.

Later, Ye and Connine (1999) used vowel and tonal monitoring tasks to investigate the tonal information in spoken word processing of Mandarin. In the first experiment, the subjects were asked to identify whether the stimuli contained the target tone and vowel combination (e.g., tone 2-/a/). The results showed that the subjects responded slower to nonword stimuli than word stimuli and had a longer reaction time to tone-mismatch stimuli than to vowel-mismatch stimuli. The results were consistent with the findings of Cutler & Taft & Chen (1992), Chen (1997), the backward shadowing task of Yip et al. (1998) and Zhou (2000) showing a vowel advantage. Ye et al. further investigated whether the late perception of tone information would also be found in idiomatic contexts. In a second experiment, three-syllable idioms were presented as contexts for the target stimuli. The target stimuli contained either the target vowel or target tone. The subjects were asked to identify whether the target stimuli were the target vowel or tone in a vowel monitoring and a tone monitoring task, respectively. The results showed that the vowel was recognized later than the tone in the idiomatic contexts. This indicated that the advantage of vowel information disappeared when the tone information was elicited from the contexts. The results also demonstrated that the vowel advantage appeared in the minimal context; however, when the pre-activated syllables provided sufficient information, the tone advantage emerged. Because the activation of toneme and lexicon interacts with each other, the authors suggested that tone processing is a perceptual processing including high lexical involvement. The third experiment further examined whether lexical activation would be influenced by the similarity between speech input and target representation. Two conditions of tone mismatch were created: close and far tone mismatch in which the third syllable tone 2 was mispronounced as tone 4 or tone 3, respectively, in the four-syllable idioms (In Mandarin, tone 2 and tone 3 are acoustically close; tone 2 and tone 4 are acoustically far), and another set of idioms were used as the target stimuli for tone and vowel monitoring tasks. The results showed that the reaction time of idioms was faster in the close mismatch condition in both tone and vowel monitoring tasks. In addition, the reaction time of the close mismatch condition was faster than the far mismatch condition. The results indicated that the activation of lexical tone is not a categorical process because tolerable tone mismatches still can be accepted. The authors suggested that tone information extracted from speech signal was served to lexical activation in a graded mode (Connine & Ye, 1997).

Recently, Yip (2001) further examined the influence of phonological relatedness of the stimuli, and found that the facilitation effect was only found when the prime and the target shared segmental structures. For example, in Yip et al.'s study (1998), 75% of the stimuli were phonologically related and the other 25% were phonologically unrelated. Previous studies (Goldinger et al., 1992; Hamburger & Slowiaczek, 1996) suggested that the phonological relatedness proportion (PRP) affects the priming performance. Therefore, Yip (2001) replicated the previous (1998) experiment with modification in which half the stimuli were phonologically related and the other half was phonologically unrelated. The results showed that the priming effect was found when the prime and the target had the same segmental structure, which was consistent with the finding of Yip et al. (1998). It indicated a superiority of segmental information in spoken word processing in tonal languages, which was in line with the findings reported by Taft & Chen (1992) Cutler & Chen (1997), Ye & Connine (1999) and Zhou (2000). Additionally, the facilitation effect was observed when the prime and the target shared rhyme and tone, which was in line with the data reported by Radeau et al. (1995) and Chen & Cutler (1997). Yip demonstrated that when listeners heard the target followed by the same rhyme syllable, recognition was facilitated. Moreover, an inhibition effect was found when the prime shared onset and tone with the target. The results were consistent with the findings of Slowiaczek & Hamburger (1992), Radeau et al. (1995) and Chen & Cutler (1997) showing competition between lexical representations of phonologically related words. Yip suggested that the Cantonese speakers are more sensitive to segmental information than tonal information in the processing of Cantonese.

Liu and Samuel (2007) further examined the role of Mandarin tones in different contextual situations. In the study, disyllabic Mandarin words were presented normally or with changed tonal or/and segmental structures (consonant mismatch, vowel mismatch, tone mismatch or all mismatch) to create five types of stimuli (e.g., *shi2-wu4* original word "food"; *chi2-wu4* consonant mismatch; *shui2-wu4* vowel mismatch; *shi3-wu4* tone mismatch; *que1-wu4* all mismatch). These stimuli were used as the target words in three contextual conditions, which were Word, Sentence or Idiom. The three contextual conditions were examined in two experiments. In Experiment 1, native Mandarin speakers were asked to make lexical decisions to three conditions. In Experiment 2, Mandarin listeners were asked to distinguish the tones and the vowels of the stimuli in white noise. The results of Experiment 1 showed that the accuracy of five types of stimuli was equivalent in the Word and Idiom conditions; however, in the Sentence condition, the subjects made more errors in the tone mismatch condition than other mismatch conditions. The findings showed a segmental advantage, which has been addressed by Taft & Chen (1992) Cutler & Chen (1997), Ye & Connine (1999) and Yip (2001) for single words. The results of Experiment 2 showed that the listeners were faster to make the tone decisions than the vowel decisions in the three contextual situations. The authors suggested that it might be because Mandarin final vowels contained similar vowels, that is, the listeners had difficulty distinguishing vowels in white noise. In addition, the accuracy for the tone mismatches was higher than the vowel mismatches in the three conditions. This indicated that the tone advantage was promoted under strong contexts. When the context provided enough information, the tone advantage appeared and the segmental advantage disappeared (Ye & Connine, 1999). Moreover, it showed that the tone information plays a more important role in the lexical processing than the segmental information.

In addition, Zhou, Qu Yanxuan, Gaskell & Marslen-Wilson (2004) used cross-modal priming lexical decision tasks to investigate how tonal information is used to constrain semantic activation in spoken word recognition of Chinese. In Experiment 1 and 2, auditory primes were disyllabic compound words that shared the same segmental structure but differed in tone in which tone-mismatches were in the first, second or both syllables, and unrelated control primes were also created. The visual probes were the words that were segmentally related to the compound words. In Experiment 3, nonword tone-mismatch primes were created by altering the initial or second tone of the word primes for the early mismatch group and the later mismatch group, respectively. In addition, in the high-similarity nonword condition, tone 2 of the critical syllable of original words was changed into tone 3 and vice versa. In the low-similarity nonwords condition, tone 2 of the critical syllable of original words was changed into tone 4, and tone 3 of the critical syllable of original words was changed into either tone 4 or tone 1. The results of Experiment 1 and 2 showed that the facilitation was only found when the auditory primes and visual targets shared the semantic meaning. It indicated that the tonal information in spoken words was immediately used to prevent unrelated lexical representation and semantic activation. Additionally, the results of Experiment 3 showed that the priming effect was found in the high-similarity nonword condition but not found in the low-similarity nonword condition. No significant semantic priming was found in early mismatch and later mismatch. It indicated that tone similarity, competition environment and position of tone alternation influenced the determination of lexical representation and semantic activation. The authors suggested that in spoken word recognition, tone information is a critical element in constraining lexical representation of spoken word in tonal languages.

Phonological overlap

Previous studies have demonstrated that the segmental and suprasegmental information are processed in the same phase to activate lexical representations during word recognition. In addition, some studies have investigated the effect of phonological priming in word recognition of lexical stress languages. For example, Slowiaczek and Hamburger (1992) used auditory single-word shadowing tasks to examine phonological priming effects. One hundred monosyllabic English words were chosen as targets. Each target was paired with four types of primes, which were identical, sharing the first three phonemes, sharing first two phonemes, sharing the first phoneme, or unrelated. The targets followed either auditory or visual primes in the experiments. The English subjects were asked to repeat the target when they heard the target. The results showed that the facilitation effect was found when the prime and the target shared the first phoneme; however, inhibition was found when the prime and the target shared more initial phonemes. The authors suggested that the activation of phonological information in word recognition starts at the prelexical level, and the phonological relatedness interferes in the later lexical activation.

Radeau, Morais and Segui (1995) used lexical decision and shadowing tasks to compare the items with beginning and final two-phoneme overlap. The stimuli were two sets of 16 monosyllabic French words. The results showed that the facilitation effect consistently occurred when the prime and the target overlapped in final portion in both lexical decision and shadowing tasks. Additionally, an inhibition effect was found when the prime and the target shared the initial two phonemes in the lexical decision task, and it was consistent with the data reported by Slowiaczek & Hamburger (1992) in the shadowing task. Slowiaczek et al. argued that the inhibition effect might result from the competition of phonologically related phonemes. Additionally, the authors suggested that if an effect occurs earlier than the lexicon, it should not transfer across different types of forms. Radeau et al. (1994) failed to find the facilitation effect of final overlap when using an auditory prime and a visual target. The result supported that the priming effect of final overlap was found across the experiments showing a prelexical locus.

McQueen and Sereno (2005) further investigated whether the facilitation and inhibition effect found in phonological overlap was due to the strategic bias or automatic process. In the experiment, 6 sets of spoken Dutch words and nonwords, which formed three types of phonological overlap between primes and targets: rhyme overlap, one-phoneme onset overlap, and three-phoneme onset overlap, were used as the stimuli. The Dutch listeners were asked to make lexical decisions on these target words. In addition, the targets were manipulated in five conditions, which differed in inter-stimulus interval (ISI) between primes and targets and the control primes. Before the experiment, the participants learned to expect particular phonological patterns in targets when given primes carried particular phonologically patterns. In the Expected-related condition, the target was expected and was phonologically and semantically related to the prime (e.g., *honk-vonk* “base-spark” for rhyme overlap). In the Expected-unrelated condition, the target was expected and was phonologically but semantically unrelated to the prime (e.g., *nest-galm* “nest-boom” for rhyme overlap). In the Unexpected-related condition, the target was unexpected but was semantically related to the prime (e.g., *nest-pest* “nest-plague” for rhyme overlap). In the Unexpected-unrelated condition, the target was unexpected and was semantically unrelated to the prime (e.g., *honk-mest* “base-manure” for rhyme overlap). The fifth condition had no primes, which was used as the baseline measure for unprimed target responses. The results showed that when the prime and target rhymed, the listeners had shorter and more accurate responses than targets that did not rhyme with primes when the ISI was shorter. It indicated that there was an automatic process that affected the performance of lexical decision. Also, the participants responded faster to expected targets than to unexpected targets showing a strategic expectancy bias. The results of one-phoneme onset overlap showed that no priming effect was found when the prime and target were one-phoneme onset overlap. It indicated that one phoneme was insufficient to facilitate automatic processing. In addition, responses were faster and more correct to expected targets than unexpected targets with the shorter and longer ISIs. It demonstrated that the listeners could learn to use phonological expectancies to influence their lexical decisions when the targets were phonologically related or unrelated to the primes. The results of three-phoneme onset overlap showed that the listeners were faster and more accurate on the targets, which phonologically overlapped with the primes than on the phonologically unrelated primes. It indicated there were automatic processes, which were also observed in the rhyme overlap condition. However, the results also showed that responses were faster and more accurate on expected targets than on unexpected targets at all ISIs. The listeners used phonological expectancies to make their lexical decisions showing a strategic bias, and it was consistent with the finding in the one-phoneme overlap condition. The authors suggested that both automatic process and strategic bias existed in phonological priming, but it is possible to take them apart and examine them separately.

Auditory Mandarin tone form priming

Recently, C.-Y. Lee (2007) used four form priming tasks to examine the role of Mandarin tones in constraining lexical activation and the time course of the activation. In direct priming tasks (Experiment 1 and 2), the prime and the target were directly related in form (e.g., *lou3* “hug”-*lou2* “hall”). In mediated priming tasks (Experiment 3 and 4), the prime was not directly form-related to the target but was form-related to a third word which was semantically related to the target but was not presented (e.g., the above example’s target was replaced by *jian4zhu2* “building”).

In the study, four types of prime were used as the stimuli and four conditions were contrasted. First, the prime and target were identical in both segmental structure and tone (e.g., *lou2* “hall”-*lou2* “hall”). Second, the prime and target overlapped only in segmental structure (e.g., *lou3* “hug”-*lou2* “hall”) but differed in tone. Third, the prime and target only overlapped in tone (e.g., *cang2* “hide”-*lou2* “hall”) but differed in segmental structure. Fourth, the prime and target shared neither segmental structure nor tone (e.g., *pan1* “climb”-*lou2* “hall”), which was an unrelated condition.

The results of direct priming task showed that a facilitation effect was found only when the prime and target were identical in both segmental structure and tone (ST). No facilitation was found when the prime shared only tone (T) or only segmental structure (S) with the target. In fact, reaction times for T and S conditions were similar to the reaction times when the prime and target did not share either tone or segmental structure (UR). In direct priming tasks (Experiment 1 & Experiment 2), two inter-stimulus intervals (ISIs) between the prime and target, 250 ms and 50 ms, respectively, were used to investigate whether the lexical activation occurred quickly in the beginning stage of word recognition and disappeared quickly. However, the short and long ISIs did not influence the results.

The author further used mediated priming tasks to examine the tonal and segmental structure overlap because such tasks are less dependent on response strategies since there is not a direct overlap in terms of form. The results showed that a priming effect was found only in the ST condition at the longer ISIs. At the shorter ISI (50 ms), however, both the ST and S conditions showed priming. Since the S primes and ST primes were minimal tone pairs and were semantically related to targets, a priming effect found in the S condition might be mediated by the ST primes which were different from the S primes only in tone. C.-Y. Lee suggested that the S primes stimulated the activation of ST primes and then further stimulated the activation of target words, which resulted in the priming effect for the S prime condition.

Overall, a facilitation effect was consistently found in ST primes in direct and mediated priming tasks, while the tone or segmental overlap by itself was not sufficient to produce a facilitation effect in direct priming tasks but segmental overlap by itself did show priming in mediated tasks at a short ISI. C.-Y. Lee suggested that tone information was used to constrain the lexical activation and block inappropriate lexical candidates in the early phase. The listeners used tone information to figure out equivocal semantic meanings and exclude the tone-mismatch competitors even though there was segmental overlap. Similarly, the listeners used segmental information to figure out meaning and exclude segmental-mismatch competitors.

While these conditions are interesting, one methodological aspect of C.-Y. Lee's experiments should be examined. In C.-Y. Lee's study, the prime and target pair combination were not equally used in the S condition. Recall that in the S condition, there was only segmental overlap and no tonal overlap. In the direct priming tasks, the tone 1-tone 4 and tone 2-tone 3 prime and target pairs were used more often than other tone pairs. Numbers of prime-target tone pairs in the S condition for the C.-Y. Lee study are listed in **Table 1**.

Table 1: Numbers of tone pairs used in the S condition for C.-Y. Lee (2007).

Prime tone	Target tone	# of pairs
1	2	5
1	3	8
1	4	10
2	1	3

2	3	8
2	4	1
3	1	8
3	2	11
3	4	7
4	1	11
4	2	3
4	3	5

Recall that **Figure 1** showed F_0 contours of a Mandarin word *ma* combined with four Mandarin tones. It shows that tone 2 and tone 3 have similar F_0 contours, which are mid-rising and low-dipping, respectively, and they also have similar mid to low frequency onsets. On the contrary, tone 1 and tone 4 both start with higher onsets of F_0. At the onset of their contour, tone 1 and tone 4 are very similar. Therefore, tone 2-tone 3 and tone 3-tone 2 as well as tone 1-tone 4 and tone 4-tone 1 pairs can be considered as the acoustically similar tone group, and other tone pairs such as tone 1-tone 2, tone 2-tone 1, tone 1-tone 3, tone 3-tone 1, tone 2-tone 4, tone 4-tone 2, tone 3-tone 4, and tone 4-tone 3 can be considered as acoustically dissimilar tone group. If you examine C.-Y. Lee's prime-target pairs, many had similar prime-target pairs (10 pairs for tone 1-tone 4; 11 pairs for tone 4-tone 1; 8 pairs for tone 2-tone 3; 11 pairs for tone 3-tone 2) while there were fewer pairs with dissimilar tones (5 pair for tone 1-tone 2; 3 pairs for tone 2-tone 1; 8 pairs for tone 1-tone 3; 8 pairs for tone 3-tone 1; 1 pair for tone 2-tone 4; 3 pairs for tone 4-tone 2; 7 pairs for tone 3-tone 4; 5 pairs for tone 4-tone 3).

The results of Ye & Connine's (1999) study demonstrated that in both vowel and tone monitoring tasks, a priming effect was observed when two tones shared fewer features, whereas, when two tones shared more features, no significant priming effect was found. That is, the tone similarity affects the lexical processing and semantic activation of the basic word. The authors suggested that if number of features that two tones shared influenced priming effects, a facilitation effect may be observed when two tones shared less features and an inhibition effect when two tones shared more features. Therefore, it is possible that the results found in C.-Y. Lee's direct priming tasks in which segmental overlap by itself did not show priming might be because an unbalanced number of tone pairs confound with the data. If prime-target pairs have equal number and balanced tone pairs, it might be expected some priming may be observed in the S condition. Furthermore, such a balanced design will allow us to examine each prime-target pair individually to observe facilitation and inhibition effect of tones on each tone pair combination.

Current study

In the current study, two experiments are conducted to extend the nature and processing of tonal information in spoken word recognition of Chinese. The present study used a direct priming task to examine whether or not the listeners are able to use tonal information to disambiguate minimal Chinese tone pairs. Experiment 1 replicated the first experiment of C.-Y. Lee’s (2007) study but with a modification that balanced tonal information in prime-target primes. That is, in the S condition, there are 4 pairs for each prime-target tone combination (e.g., 4 for tone 1-tone 2; 4 for tone 1-tone 3; 4 for tone 1-tone 4; 4 for tone 2-tone 1; 4 for tone 2-tone 3; 4 for tone 2-tone 4; 4 for tone 3-tone 1; 4 for tone 3-tone 2; 4 for tone 3-tone 4; 4 for tone 4-tone 1; 4 for tone 4-tone 2; 4 for tone 4-tone 3).

If tonal and segmental information function to clarify the ambiguous word meanings, a facilitation effect may be found when the prime and target words are identical in both tonal and segmental structures. Also, if tonal information is immediately used to constrain lexical and semantic activation effects, a facilitation effect may be found in tone overlap pairs as well and there may be no facilitation effects when the prime and target pairs only have the same segmental structure. If, however, tonal information is not immediately used to block inappropriate lexical candidates, facilitation may not be found when prime and target have segmental overlap only.

Experiment 2 extends the prime-target primes paradigm to include minimal overlap in onset and offset portion. If the segmental information shows superiority, the priming effect may be found when the prime and target share the offset and tone. However, if the tonal information is immediately used to eliminate impossible lexical candidates, the facilitation effect may be found when the prime and target share the onset segmental information.

Method

Experiment 1

The purpose of Experiment 1 was to further examine the result of C.-Y. Lee's (2007) direct priming experiment. He found no priming effect when the prime and target shared only segmental structure (S), tone (T) or neither (UR). However, for the S condition, prime-target pairs were not equally often presented to participants.

Some tone prime-target of pairs occurred more often than other prime-target tone pairs. The findings in his study might be due to the presence of more similar prime-target pairs such as tone 1-tone 4 pairs compared to tone 1-tone 2 pairs. Therefore, the current experiment replicated C.-Y. Lee's direct form priming experiment in which the targets were paired with four types of primes: the prime and target were identical in both tone and segmental structure (ST), shared only segmental overlapped (S), shared only tone (T) or shared neither tone nor segmental structure (UR). More importantly, in the current experiment, the prime-target tonal pairs had balanced tonal presentation.

Stimuli

Forty-eight monosyllabic Mandarin words were chosen as targets. Each target was paired with four types of primes; therefore, there were 48 primes in each condition. In the ST condition, the primes and targets completely overlapped in segment and tone (e.g., *bo-bo1*). In the S condition, only the segmental structure of the primes and targets overlapped (e.g., *bo2-bo1*). There were 4 pairs for each prime-target tone combination (e.g., 4 for tone 1-tone 2; 4 for tone 1-tone 3; 4 for tone 1-tone 4; 4 for tone 2-tone 1; 4 for tone 2-tone 3; 4 for tone 2-tone 4;

4 for tone 3-tone 1; 4 for tone 3-tone 2; 4 for tone 3-tone 4; 4 for tone 4-tone 1; 4 for tone 4-tone 2; 4 for tone 4-tone 3). In the T condition, the primes and targets shared tone only (e.g., *zhua1-bo1*). In the UR condition, the primes shared neither segmental structure nor tone with targets (e.g., *man3-bo1*). Additionally, 48 monosyllabic, pronounceable nonwords, in which 45 nonwords were selected from C.-Y. Lee's nonword list and 3 nonwords were created from Da's (1998) corpus, were used in the experiment. These nonwords were paired with the same prime lists and functioned as fillers. The word and nonword stimuli used in the experiment are listed in **Appendix 1**.

Monosyllabic Mandarin words were selected as primes and targets in the experiment. All word stimuli were formed with CV and CVC syllables. The word frequency count was from Da's (1998) corpus in which 45 million characters of simplified Chinese texts were analyzed from different online sources. For the present experiment, the frequency of word stimuli was controlled. The frequencies of ST, S, T, and UR primes were 84345, 82762, 93975 and 83009, respectively, according to a corpus of 45 million words (Da, 1998). There was no significant difference among the four types of primes in terms of frequency of occurrence: $F(3, 188) = .074$, $p = .97$.

A male native speaker of Mandarin Chinese recorded stimuli in an anechoic chamber at University of Kansas using a Marantz PMD671 solid-state recorder and an Electro-Voice RE20 microphone. After recording, the data was immediately transferred to a PC. The sampling rate was 44.1kHz. The digital recording was then analyzed using Praat at 22kHz onto a PC. Onsets and offsets of each stimulus were identified using both visual and auditory criteria and each stimulus including the 48 words, the 48 nonword and the 144 prime words (48 in each condition, ST, S, T and UR) were saved as individual files.

In the experiment, each target was paired with only one prime and was presented only once to each subject. Therefore, no target was repeated in the experiment. Twelve primes from each type of prime (ST, S, T and UR) were paired with word and nonword targets. Four lists were created in which the targets were randomly paired with four types of prime (ST, S, T and UR). Each list had 96 trials (48 words, 48 nonwords targets). The targets were the same across lists, but they were paired with different types of primes. Therefore, the participants were not hearing the same target stimuli more than once during the experiment.

Participants

Twenty native speakers of Mandarin Chinese (9 females, 11 males) at the University of Kansas volunteered to participate in the experiment. No subjects had any history of hearing impairment or language disorder. The subjects have been in America no more than five years. A brief questionnaire was given to determine language background (see **Appendix 3**). The range was from 18 to 35. The average age was 26. The participants are able to speak one or two Chinese dialects, but spoke Mandarin in their daily lives.

Procedure

The experiment started with Chinese instructions. Primes followed by targets, 250 ms inter-stimulus interval (ISI) between primes and targets in a trial, and a 4-second inter-trial interval between each pair. The experiment of each session was approximately 15 minutes. The experiment was conducted using Paradigm (an experimental design software by Tagliaferri[1]) in the University of Kansas Phonetics and Psycholinguistics Laboratory.

The subjects participated in the experiment individually. They sat in a quiet

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1 http://www.perceptionresearchsystems.com/

room at the University of Kansas Phonetics and Psycholinguistics Laboratory. The subjects were randomly assigned to listen to one of the four lists over headphones. Before the experiment, the experimenter explained the procedures of the auditory lexical decision priming experiment to the subjects in Mandarin Chinese, and the instructions were written in a simplified form of Chinese, used in Mainland China.

In order to let the subjects become familiar with the operation of the experiment, eight practice trials, which included four word and four nonword targets, were presented before the experiment. The subjects were asked to identify whether the last item in the pair of stimuli is a word or nonword by pressing the response button which was marked “是”(Yes) and “不是”(No), respectively. The subjects were asked to respond as quickly and accurately as possible. The reaction time and errors data were recorded and saved on the computer for each participant.

Results

In the experiment, reaction time, which was measured from onset of targets and response accuracy of targets were recorded by Paradigm and analyzed by separate analyses of variance (ANOVAs). Reaction times above or below 2 standard deviations of each subject's mean were excluded. **Table 2** shows means of reaction time and standard deviations (in parentheses) for the four types of prime. They were 1095 ms (196), 1123 ms (171), 1236 ms (241), and 1190 ms (215) for ST, S, T, and UR, respectively. The mean reaction times with standard errors are shown in **Table 2** and **Figure 2** for each of the four conditions.

A one-way repeated measures ANOVAs showed a significant effect of prime type: F (3, 141)= 5.467, p= .001. Pairwise comparisons showed that when compared to the baseline (UR) condition, the listeners responded 95 ms faster when targets were preceded by ST primes (p= .017). The listeners also responded 67 ms faster when targets were preceded by S primes (p= .028). However, there was no significant difference when targets were preceded by T primes (p= .322; 46 ms slower). The mean reaction time of targets followed ST primes was similar to that following S primes (p= .439; 28 ms faster). Overall, ST and S were similar to each other, and they were faster than T and UR, which showed no difference.

Table 2: Mean reaction times and standard deviations for ST, S, T, and UR in Experiment 1.

Prime Type	**Reaction Time (ms)**	**SD**
ST (*bo1-bo1*)	1095	196
S (*bo2-bo1*)	1123	171
T (*zhua1-bo1*)	1236	241
UR (*man3-bo1*)	1190	215

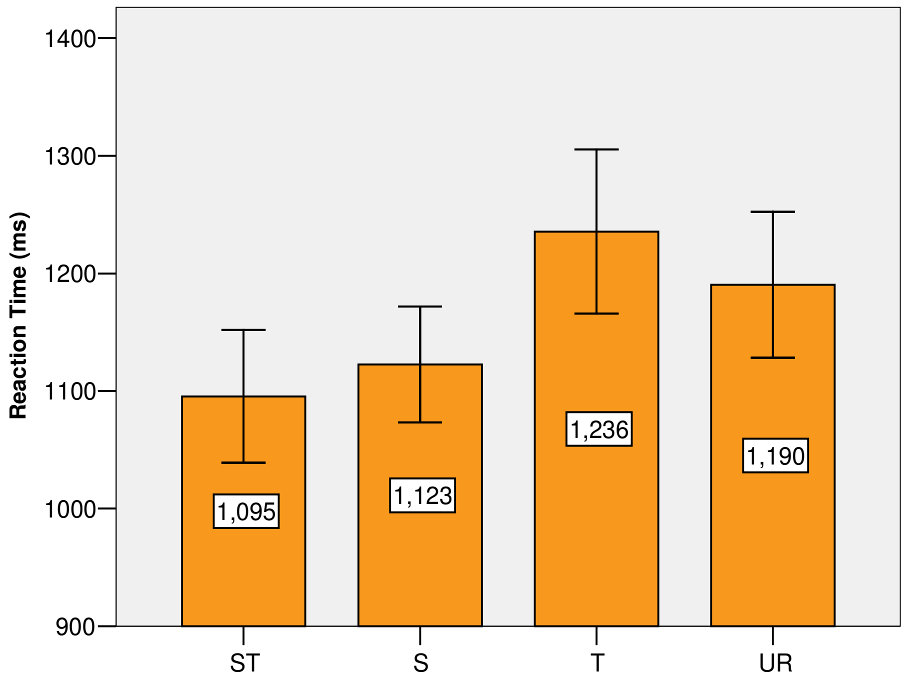

Figure 2: Mean reaction times and standard errors of ST, S, T, and UR in Experiment 1.

Table 3 showed the mean number of errors made by subjects in four conditions (ST, S, T, and UR). One-way repeated measures ANOVAs showed a significant effect of types of prime: F (3, 141)= 5.729, p= .001. Pairwise comparisons showed that the subjects made more errors in the UR condition compared to the ST condition (p= .027), and in the UR condition compared to S condition (p= .007). However, the UR condition was not significantly different from the T condition (p= .439). The result was similar to the reaction time data, ST similar to S and both faster than the T and UR condition, which were not significantly different.

Table 3: Mean errors in Experiment 1.

Prime Type	**Mean errors**
ST (*bo1-bo1*)	15
S (*bo2-bo1*)	10
T (*zhua1-bo1*)	38
UR (*man3-bo1*)	46

S condition

According to tone similarity, tone pairs in the S condition were divided into two groups: acoustically similar tones, which were tone 2-tone 3, tone 3-tone 2, tone 4-tone 1, and tone 1-tone 4 pairs (SimTone) and acoustically dissimilar tones, which were the other tone pairs (tone 1-tone 2, tone 1-tone 3, tone 2-tone 1, tone 2-tone 4, tone 3-tone 1, tone3-tone 4, tone 4-tone 2 and tone 4-tone 3) (NotSimTone). A t-test showed that there was no significant difference, although mean reaction time of NotSimTone was 77 ms faster than SimTone, t (46)= -1.484, p= .145. Listeners responded slightly faster to NotSimTone than SimTone. **Figure 3** shows mean reaction times of ST, SimTone, NotSimTone, T, and UR.

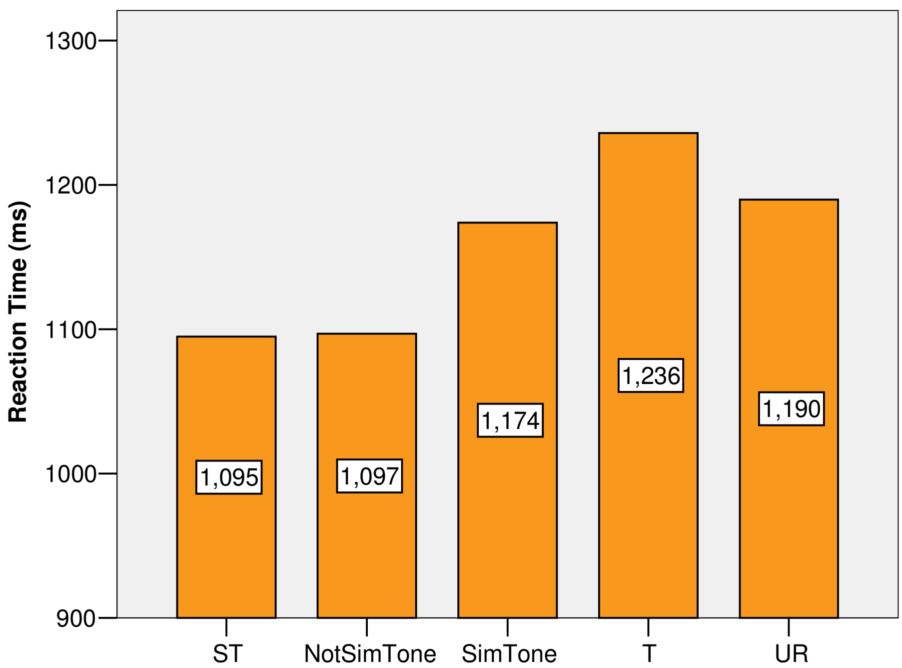

Figure 3. Mean reaction times of ST, NotSimTone, SimTone, T, and UR in Experiment 1.

T condition

A one-way repeated measures ANOVAs was used to compare tone pairs in the T condition. It showed no significant difference was found among four tone pairs: F (3, 33)= .701, p= .558. However, a pairwise comparison showed that there was a trend towards inhibition when tone 3 pairs were compared to tone 4 pairs (p= .089). **Figure 4** shows the mean reaction times and standard errors of four tone pairs in the T condition.

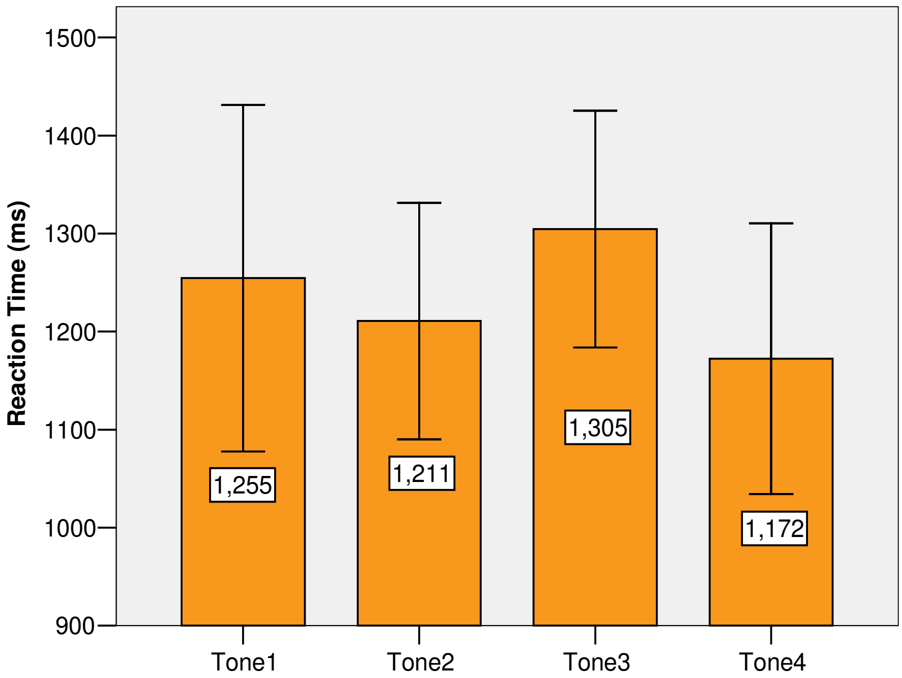

Figure 4: Mean reaction times and standard errors of four tone pairs in T.

Summary

The results of Experiment 1 showed that a priming effect was found when the prime and target were identical (ST) or only segmental structure overlapped (S). The listeners responded faster to the targets when preceding primes, which shared both tone and segmental information, or only segmental structure. In addition, the listeners made more errors when the prime and target shared only tone information (T) or neither (UR) than those that shared both tone and segmental structure (ST) or only segmental structure (S). The error data were consistent with the results of reaction time for the four types of primes. In the S condition, the primes were divided into two groups according to tone similarity. Although there was no significant difference between these two groups, the listeners responded slightly faster when the prime and target shared fewer features (NotSimTone) than those shared more features (SimTone). In the T condition, four tone pairs were analyzed. Although there was no significant difference among four tone pairs, tone 3 pairs had slightly the longer reaction times than tone 4 pairs.

Experiment 2

The goal of Experiment 2 was to investigate whether the prime and target that share partial onset or offset phonemes can facilitate subjects to identify Chinese spoken words. The experiment design was the same as Experiment 1. The priming effect of final overlap was found in both shadowing and lexical decision tasks (Radeau et al., 1994, 1995; Chen et al., 1997; Yip, 2001). Therefore, if the superiority of segmental information facilitates the lexical selection, the priming effect may be found when the prime and target share the segmental offset information and tone. However, if the tonal information is immediately used to eliminate impossible lexical candidates, the priming effect may only be found when the prime and target share the segmental onset information.

Stimuli

In Experiment 2, targets were paired with four types of primes, which were ST, T+Onset, T+Offset and UR. The ST and UR conditions were the same as Experiment 1. Two different types of primes were created, which were T+Onset and T+Offset. In the T+Onset condition, the prime and target shared only the tone and the consonantal onset of the syllable (e.g., *bin1-bo1*). In the T+Offset condition, the prime and target shared only the tone and offset of the syllable (e.g., *po1-bo1*), which could be either the V or the final VN offset.

Four lists were generated in which the targets were randomly paired with one of four types of prime. No targets were paired with the prime more than once. Each list had 96 trials including 48 word and 48 nonword targets, and they were the same across lists. The targets were the same as those used in Experiment 1.

The word frequencies were also controlled. The frequencies of ST, T+Onset, T+Offset and UR primes were 84345, 89774, 106214 and 83009, respectively according to a corpus of 45 millions words (Da, 1998). There was no significant difference among the four types of primes, F (3, 188)= .380, p= .77. The stimuli used in the experiment 2 are listed in **Appendix 2**.

The experiment started with Chinese instructions, followed by prime-target pairs, a 250 ms inter-stimulus interval (ISI) between prime-target pairs, and then a 4-second inter-trial interval. The setup of Experiment 2 was the same as Experiment 1. The experiment lasted approximately 15 minutes.

Participants

Twenty native speakers of Mandarin Chinese (10 females, 10 males) at the

University of Kansas volunteered to participate in the experiment. None of them had any unknown hearing impairments. No subject had participated in Experiment 1. No subjects lived in America more than five years. A brief questionnaire was given to determine language background. The range of age was from 20 to 36. The average age was 25.8. The participants are able to speak one or two Chinese dialects, but spoke Mandarin in their daily lives.

Procedure

The procedures were the same as Experiment 1.

Results

In the experiment, reaction time, which was measured from onset of targets, and response accuracy of targets were recorded by Paradigm and analyzed by separate analyses of variance (ANOVAs). The data above or below 2 standard deviations were excluded. **Table 4** shows mean reaction times and standard deviations for the four types of prime. The mean reaction times with standard errors are shown in **Figure 5**. A one-way repeated measures ANOVAs showed a strong trend of prime type: F (3, 141)= 2.540, p= .059. Pairwise comparisons showed that none of the conditions were significantly different when compared to the baseline (UR) condition. The listeners responded 54 ms faster when targets were preceded by ST primes (*p*= .293), they responded 50 ms slower when targets were preceded by T+Offset primes (*p*= .298), and they responded 59 ms slower when targets were preceded by T+Onset primes (*p*= .133). Comparing between conditions, one pairwise comparison did show a significant difference, the mean reaction time of targets following ST primes was 113 ms faster than those following T+Onset primes (*p*= .023).

Table 4: Mean reaction times and standard deviations in Experiment 2.

Prime Type	**Reaction Time (ms)**	**SD**
ST (*bo1-bo1*)	1047	232
T+Onset (*bin1-bo1*)	1160	226
T+Offset (*po1-bo1*)	1151	233
UR (*man3-bo1*)	1101	193

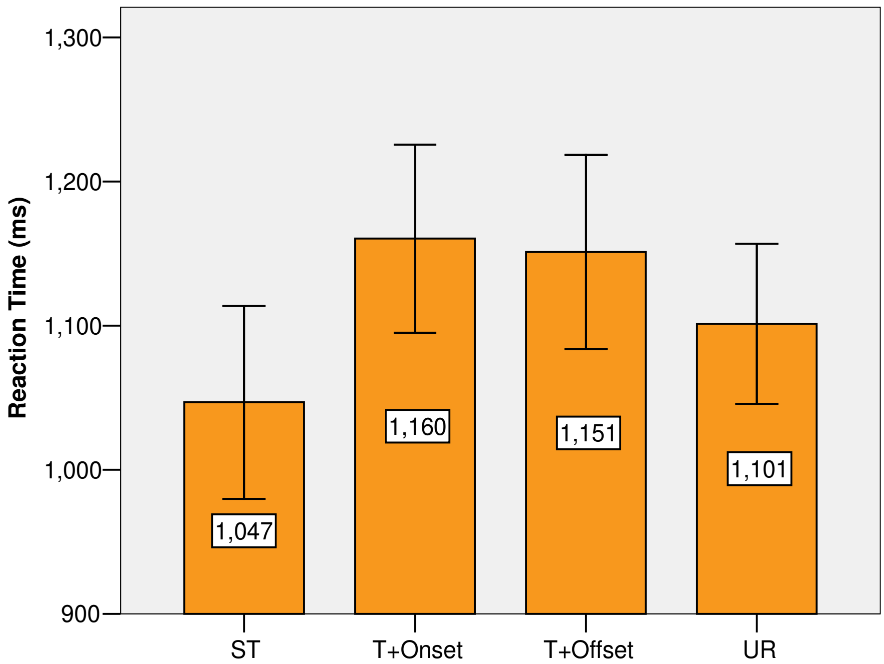

Figure 5: Mean reaction times and standard errors of ST, T+Onset, T+Offset, and UR in Experiment 2.

Table 5 shows the mean errors made by subjects in four conditions (ST, T+Onset, T+Offset, and UR). One-way repeated measures ANOVAs showed there was no significant effect for the four types of prime: F (3, 141)= 1.336, p= .265. However, there was a trend towards an effect since listeners made more errors when the prime and target shared tone and onset of segmental information (p= .132) compared to the baseline (UR) condition. The error data are similar to the reaction time data.

Table 5: Mean errors in Experiment 2.

Prime Type	**Mean errors**
ST (*bo1-bo1*)	27
T+Onset (*bin1-bo1*)	42
T+Offset (*po1-bo1*)	25
UR (*man3-bo1*)	19

T+Onset

In addition, in the T+Onset condition, a t-test was used to compare mean reaction times of targets following primes with an initial sonorant (*lin2-lu2*) compared to with an initial obstruent (*bin1-bo1*). While the overall reaction times showed that the listeners responded 133 ms faster to targets following prime-target pairs with an initial obstruent than those following prime-target pairs with an initial sonorant, this effect did not reach significant (p= .099). **Table 6** shows mean reaction times and standard deviations of targets following prime-target pairs with an initial sonorant and prime-target pairs with an initial obstruent.

Table 6: Mean reaction times and standard deviations of targets followed primes with an initial sonorant and primes with an initial obstruent.

Prime Type	**Reaction time (ms)**	**SD**
Initial obstruent (*bin1-bo1*)	1055	196
Initial sonorant (*lin2-lu2*)	1188	227

T+Offset

In the T+Offset condition, a t-test was used to compare mean reaction times of targets following primes, which were CV, CVC, CGV, and CGVC structure (C= consonant; G= glide; V= vowel). **Table 7** shows mean reaction times of CV, CVC, CGV, and CGVC. The results showed that when the prime and target had successively more overlap, the listeners did not respond slower than to those conditions with less overlap. Although no significant effect was found between less overlap (CV) and more overlap (CGVC)(p= .868), the listeners responded 13 ms faster when prime-target pairs overlapped less.

Table 7: Mean reaction times of CV, CVC, CGV, and CGVC in the T+Offset condition.

Prime Type	**Reaction time (ms)**
CV (*po1-bo1*)	1124
CVC (*deng1-zeng1*)	1108
CGV (*tuo1-guo1*)	1206
CGVC (*chuan1-huan1*)	1137

ST

Finally, a t-test was used for comparing ST in Experiment 1 and 2. There was no significant difference in ST in the two experiments (p= .243). Also, a t-test was used to compare errors in the ST condition in the two experiments; no significant difference was found (p= .135). **Table 8** shows mean reaction times, standard deviations and errors of ST in Experiment 1 and 2.

Table 8: Mean reaction times, standard deviations, and errors of ST in Experiment 1 and 2.

Prime Type	**Reaction time (ms)**	**SD**	**Mean errors**
ST in Exp. 1 (*po1 – bo1*)	1095	196	.15
ST in Exp. 2 (*po1 – bo1*)	1047	232	.27

Summary

The results of Experiment 2 showed that no significant difference was found between UR and ST, and T+Onset, and T+Offset. A priming effect was found when the prime and target were identical (ST) compared to targets that were preceded by primes which shared tone and the onset of the syllable (*bin1-bo1* for T+Onset). In addition, the T+Onset primes were further analyzed as to whether the initial consonant (a sonorant or obstruent) could influence the phonological priming. The results showed that there was a trend towards priming when the primes started with an obstruent. Additionally, the T+Offset primes were examined by overlap patterns (CV, CVC, CGV, and CGVC). The results showed little difference when the prime and target had more overlap; the reaction time was slightly longer than those that had less overlap.

Discussion

In the current study, two experiments were conducted. The purpose of Experiment 1 was to examine whether tone overlap or segmental structure overlap could facilitate the processing of Chinese spoken word recognition. In addition, the effect of acoustic similarity of prime-target tone pairs was investigated. Experiment 2 further investigated whether partial segmental overlap either in onset portion or offset portion could result in phonological priming. In the T+Onset condition, the effect of primes with an initial sonorant or an initial obstruent in onset segment overlap was evaluated.

In the present study, Experiment 1 was similar to C.-Y. Lee's (2007) direct priming experiment but with a significant modification that balanced tonal information in prime-target pairs. Therefore, prime-target pairs were equally presented to the subjects. There were four types of primes in Experiment 1: the primes and targets completely overlapped in segment and tone (ST), only the segmental structure of the primes and targets overlapped (S), the primes and targets shared tone only (T), or the primes shared neither segmental structure nor tone with targets (UR).

The results of Experiment 1 showed that a significant priming effect was found when the prime and target shared both segment and tone (ST) or shared only segmental structure (S). Although there was no significant difference found when the prime and target shared only tone information (T) compared to the UR baseline condition, there was a trend towards an inhibition effect.

Examining tone similarity, the S primes were divided into two groups. The results showed that although there was no significant difference between acoustically similar tones (SimTone) and acoustically dissimilar tones (NotSimTone), there was a trend towards a priming effect in acoustically dissimilar tones compared to acoustically similar tones. Listeners responded faster when targets were preceded by primes which were acoustically dissimilar tones (NotSimTone) than those that were preceded by primes which were acoustically similar tones (SimTone). Additionally, no significant difference was found among the four tone pairs in the T condition. But a pairwise comparison showed that there was a trend towards inhibition when tone 3 pairs were compared to tone 4 pairs (p= .089). It revealed that tone 3 pairs had the longest reaction time compared to other tone pairs.

A facilitation effect was found when the prime-target pairs were identical or only overlapped in segmental structure compared to conditions where the prime-target pairs only overlapped in tone or were unrelated. The recent results are inconsistent with C.-Y. Lee's findings where a priming effect was only found when the prime and target were identical in the direct priming task. He concluded that no priming was observed when the prime and target were only tone mismatch (S) because tone mismatch affected recognition processes. That is, he claimed that tonal information was used on-line to constrain inappropriate lexical representations. However, in the current study, a priming effect was observed when the prime and target had segmental overlap but had tonal mismatch (S). This present result indicates no or little use of tonal information at an early stage of lexical activation. In the present experiment, tone mismatch did not influence recognition processes.

The inconsistent findings between the present results and C.-Y. Lee (2007) might be because C.-Y. Lee used unbalanced prime-target pairs, while in the current study, balanced prime-target pair combinations were used in the S condition. That is, there was same number of tone combinations. Since a priming effect was observed when the prime and target were only mismatched in tone, we looked at prime-target tone combinations separately to investigate whether tone similarity would facilitate or inhibit processing. To accomplish this, the S primes were divided into two groups, which were acoustically similar tones (SimTone) and acoustically dissimilar tones (NotSimTone). In Ye & Connine's (1999) study, a priming effect was found in the close tone mismatch condition (sharing fewer features) compared to the far tone mismatch condition (sharing more features) in both vowel and tone monitoring tasks. Ye and Connine suggested that although tone was considered in a categorical fashion, when mapped onto the lexical representation, tone information could influence the acoustic similarity between two lexical representations. Consequently, when two tones shared more features, there was a stronger lexical competition than tones sharing fewer features. Therefore, the listeners needed more time to clarify word meanings and it resulted in an inhibition.

In the current study, although there was no significant difference between SimTone and NotSimTone, the listeners responded 77 ms faster to NotSimTone than to SimTone. There was a trend towards facilitation when the prime and target shared fewer features, and more inhibition occurred when two tones shared more features, which was consistent with findings from Ye et al. (1999). In C.-Y. Lee's study, more tone 1-tone 4, tone 4-tone 1, tone 2-tone 3, and tone 3-tone 2 pairs were used, that is, more similar prime –target combinations were used in the S condition. It might be predicted that there was less or no priming in C.-Y. Lee (2007) because of the unbalanced prime- target pair combination. The findings of the current study showed that when the prime and target were acoustically similar tones, there was less priming, that is, listeners used more mismatching tonal information to constrain access of lexical activations. On the contrary, when the prime and target were acoustically dissimilar tones, there was more priming, that is, listeners used less mismatching tonal information to constrain access.

This conclusion of the current study was supported by C.-Y. Lee's mediated priming tasks at the shorter ISI where a priming effect was found in the S condition showing that mismatching tonal information does not constrain lexical access. While C.-Y. Lee's stimuli were not balanced (the same set used in direct and mediated priming tasks), the priming effect that was found in mediated tasks might be because decisions were not made on competing targets (i.e., mediated priming task). Acoustical similarity may play less of a role, and this may be the case at short ISIs. Therefore, priming was observed in the S condition in mediated priming at short ISIs. When we balanced the stimuli, we could observe the priming in the S condition in direct priming even at longer ISIs.

Although tone mismatch does not seem to interfere, when segmental priming is present, tonal similarity of prime-target pairs did contribute to the priming effect. Thus some tone information did play a role during lexical processing. Additional evidence comes from a priming effect, which was found when the prime and target were identical (ST) compared to when they overlapped only in tone (T). Tonal information by itself interferes with lexical access. In addition, the results of Experiment 1 showed that listeners responded slower and made more errors in using tonal information than in using segmental information. A priming effect was found when prime and target overlapped only in segmental structure (S) showing that segmental information was used to activate lexical processing. Moreover, there was a significant difference between S and T. Cutler & Chen (1997) demonstrated that tone information is not realized early. Because tone information usually accompanies vowel information, thus when vowel information, which carries the tone, is available, tone information could be processed showing a tone disadvantage compared to segmental (vowel) information during lexical processing. Therefore, no priming but inhibition was found when the prime and target shared only tone in the present study might be because the tone information was not immediately used to constrain lexical and semantic activation effects, consequently producing an inhibition effect. The result was consistent with the findings of Taft & Chen (1992) Cutler & Chen (1997), Ye & Connine (1999), and Zhou (2000).

Experiment 2 was conducted to further investigate tonal overlap in more detail. When the prime and target share tone, the question was whether the partial overlap of the onset or offset of the syllable would disrupt priming. Therefore, in Experiment 2, there were four types of primes: the prime and target were identical (ST), the prime and target shared only the tone and the onset of segmental information (T+Onset), the prime and target shared only the tone and the offset of segmental information (T+Offset), and the prime and target did not share segment and tone (UR).

While the results of Experiment 2 showed no significant difference among the four conditions, there was a strong trend among ST, T+Onset, T+Offset, and UR ($p = .059$). A pairwise comparison showed that a priming effect was found when the prime and target were identical (ST) compared to targets preceded by primes which shared tone and onset of the syllable (T+Onset) ($p = .023$).

The T+Onset primes were further examined whether the primes with an initial sonorant or with an initial obstruent could interfere with lexical activation. The results revealed that there was a strong trend towards a priming effect when targets were preceding primes with an initial obstruent. Moreover, in the T+Offset condition, the prime-target pairs were further analyzed according to overlap patterns which were CV, CVC, CGV, and CGVC (C= consonant; G= glide; V= vowel). The results of T+Offset showed that no significant difference was found among the four overlap patterns. Listeners did not respond slower when the prime and target had more overlap than those that had less overlap. Finally, mean reaction times of ST in Experiment 1 and 2 were compared, but no significant difference was found.

The results of Experiment 2 showed no significant effect was found among the four conditions, but a pairwise comparison revealed that a priming effect when the prime-target pairs were identical (ST) compared to those shared tone and onset of segmental information (T+Onset) (p= .023). In addition, there was a trend towards inhibition when the targets were preceded by primes which shared tone and onset of the syllable (T+Onset) compared to the baseline (UR) condition (p= .133). Although no priming effect was found between T+Onset and T+Offset condition, there was a slight facilitation when prime and target shared tone and offset of segmental information (T+Offset) compared to those sharing tone and onset of segmental information with primes (T+Onset). The result might be because when the prime and target shared tone and onset of segmental information, there was a slightly greater competition among phonologically related words and it slowed recognition processes. The findings indicated that tone information was not activated initially; therefore, it was not able to constrain word meanings so quickly and further resulted in an inhibition effect. In addition, the slight facilitation effect of T+Offset compared to T+Onset might be because the prime and target shared the rhyme showing a rhyme priming effect. The prime-target pairs in the T+Offset condition only differed in the initial consonant; therefore, a slight priming might be because of a vowel advantage, which is the segment associated with the highest activity in the syllable (Radeau et al., 1995).

Since no priming but inhibition was found when the targets were preceded by primes which shared tone and initial consonant, the T+Onset condition was further examined whether the target with an initial sonorant or with an initial obstruent would interfere with lexical activation. Although there was no significant difference between targets with an initial sonorant and those with an initial obstruent, there was a trend towards more inhibition when targets had an initial sonorant. The results might be because voicing in the sonorant starts earlier than in the obstruent. Tonal information was available earlier. Therefore, the listeners responded slower when the targets had an initial sonorant than those that had an initial obstruent.

Additionally, the T+Offset primes were further examined according to overlap patterns, which were CV, CVC, CGV, and CGVC. Although no significant efffect was found, when the prime and target had more successive overlap, it slightly slowed recognition processing, whereas, when prime-target pairs had less successive overlap, it slightly speeded lexical activation. The findings indicated that little interference occurs when the amount of shared phonemes increases. In English, when the number of shared phonemes between prime and target increased in word initial position, the reaction time increased (Slowiaczek, Nusbaum & Pisoni, 1987; Slowiaczek & Hamburger, 1992). The listeners were sensitive to internal segmental structures during word recognition. In addition, when the amount of overlap between prime and target increased, the word candidates competed with neighbors at the lexical level.

Together, the present data indicate that while tone information may play a role in recognition processing, the tone information was not activated in the initial phase of lexical activation. It was not immediately used to block inappropriate lexical candidates. Although no significant effect was found between acoustically similar tones and acoustically dissimilar tones in the condition, when only segmental information overlapped, there was a trend towards priming when targets were preceded by primes which were acoustically dissimilar tones compared to those preceded by primes which were acoustically similar tones. This indicates that tone does function to make a difference in constraining lexical access. Additionally, segmental information can facilitate word recognition, and segmental information seems to carry more weight than tonal information in the processing of spoken Chinese.

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Appendix 1: Stimuli used in Experiment 1

Targets		Primes			
Word	Nonword	ST	S	T	UR
bo1	mang1	bo1	bo2	zhua1	man3
guo1	ran1	guo1	guo2	can1	si3
bi1	jiong1	bi1	bi2	suan1	han3
sui1	rong1	sui1	sui2	ca1	lan3
tie1	min1	tie1	tie3	san1	qun2
huan1	fou1	huan1	huan3	jie1	fo2
tui1	mou1	tui1	tui3	sang1	fen2
tao1	ruan1	tao1	tao3	jiu1	run4
zeng1	nuo1	zeng1	zeng4	gua1	ruo4
zang1	niao1	zang1	zang4	bei1	kuo4
chan1	rui1	chan1	chan4	gu1	cuo4
heng1	kao1	heng1	heng4	xiao1	liao2
kang2	yue2	kang2	kang1	su2	chui1
hong2	shuan2	hong2	hong1	ze2	lue:4
pa2	chuo2	pa2	pa1	xun2	kui4
lu2	zang2	lu2	lu1	pang2	cang1
lou2	suan2	lou2	lou3	xiang2	jiang1
zhe2	nie2	zhe2	zhe3	nin2	shan4
rao2	ka2	rao2	rao3	xu2	geng4
cheng2	le2	cheng2	cheng3	xi2	dai1
niang2	zhun2	niang2	niang4	mou2	duo3
xia2	pou2	xia2	xia4	hou2	zhen3
tu2	dong2	tu2	tu4	meng2	xing3
pi2	dian2	pi2	pi4	chong2	kuan3
pao3	sai3	pao3	pao1	zen3	jun4
biao3	nen3	biao3	biao1	ren3	cong1
qian3	mie3	qian3	qian1	lu:3	le4
zao3	run3	zao3	zao1	qing3	die1
chuang3	miu3	chuang3	chuang2	di3	shi1
zuo3	lue3	zuo3	zuo2	gai3	te4
du3	te3	du3	du2	lao3	hen4
cao3	die3	cao3	cao2	leng3	sun1

Appendix 1 (continued): Stimuli used in Experiment 1

Targets		Primes			
Word	Nonword	ST	S	T	UR
shuai3	xiong3	shuai3	shuai4	ken3	ceng2
kan3	teng3	kan3	kan4	niu3	liu2
guang3	nue3	guang3	guang4	ji3	lei2
lian3	niang3	lian3	lian4	fou3	de2
cha4	ken4	cha4	cha1	nong4	hui3
fan4	lia4	fan4	fan1	shou4	nu:3
dun4	fo4	dun4	dun1	ta4	ma3
shai4	qiong4	shai4	shai1	hun4	long3
nao4	neng4	nao4	nao2	pei4	ling2
cun4	gei4	cun4	cun2	gao4	fa2
mai4	de4	mai4	mai2	ku4	lun2
mi4	qun4	mi4	mi2	fang4	kua1
tong4	dei4	tong4	tong3	se4	diu1
nu4	nin4	nu4	nu3	zha4	mang2
ru4	diu4	ru4	ru3	sha4	qin1
quan4	kei4	quan4	quan3	lie4	xie1

Appendix 2: Stimuli used in Experiment 2

Targets		Primes			
Word	Nonword	ST	T+onset	T+offset	UR
bo1	mang1	bo1	bin1	po1	man3
guo1	ran1	guo1	gan1	tuo1	si3
bi1	jiong1	bi1	bao1	qi1	han3
sui1	rong1	sui1	sen1	zhui1	lan3
tie1	min1	tie1	tun1	bie1	qun2
huan1	fou1	huan1	hei1	chuan1	fo2
tui1	mou1	tui1	tan1	gui1	fen2
tao1	ruan1	tao1	ting1	sao1	run4
zeng1	nuo1	zeng1	zai1	deng1	ruo4
zang1	niao1	zang1	zu1	gang1	kuo4
chan1	rui1	chan1	che1	ban1	cuo4
heng1	kao1	heng1	hu1	feng1	liao2
kang2	yue2	kang2	ke2	tang2	chui1
hong2	shuan2	hong2	huai2	rong2	lue:4
pa2	chuo2	pa2	ping2	na2	kui4
lu2	zang2	lu2	lin2	fu2	cang1
lou2	suan2	lou2	lang2	chou2	jiang1
zhe2	nie2	zhe2	zhu2	ge2	shan4
rao2	ka2	rao2	reng2	mao2	geng4
cheng2	le2	cheng2	chai2	beng2	dai1
niang2	zhun2	niang2	nuo2	liang2	duo3
xia2	pou2	xia2	xue2	jia2	zhen3
tu2	dong2	tu2	tai2	chu2	xing3
pi2	dian2	pi2	peng2	li2	kuan3
pao3	sai3	pao3	pin3	chao3	jun4
biao3	nen3	biao3	bu3	miao3	cong1
qian3	mie3	qian3	qu3	xian3	le4
zao3	run3	zao3	zui3	kao3	die1
chuang3	miu3	chuang3	chi3	huang3	shi1
zuo3	lue3	zuo3	zi3	huo3	te4
du3	te3	du3	dang3	mu3	hen4
cao3	die3	cao3	ci3	dao3	sun1
shuai3	xiong3	shuai3	sheng3	guai3	ceng2

Appendix 2 (continued): Stimuli used in Experiment 2

Targets		Primes			
Word	Nonword	ST	T+onset	T+offset	UR
kan3	teng3	kan3	kou3	dan3	liu2
guang3	nue3	guang3	gei3	shuang3	lei2
lian3	niang3	lian3	luo3	nian3	de2
cha4	ken4	cha4	chen4	la4	hui3
fan4	lia4	fan4	fei4	pan4	nu:3
dun4	fo4	dun4	diao4	gun4	ma3
shai4	qiong4	shai4	shun4	pai4	long3
nao4	neng4	nao4	nie4	hao4	ling2
cun4	gei4	cun4	cai4	kun4	fa2
mai4	de4	mai4	mo4	sai4	lun2
mi4	qun4	mi4	men4	ni4	kua1
tong4	dei4	tong4	ti4	zong4	diu1
nu4	nin4	nu4	nai4	cu4	mang2
ru4	diu4	ru4	re4	pu4	qin1
quan4	kei4	quan4	qie4	xuan4	xie1

Appendix 3: Language background questionnaire

Participant #: ________

语言背景问卷

姓名： ____________________ 生日: __________

出生地：______________________________

就读小学所在地：______________________________

就读中学所在地：______________________________

就读大学所在地：______________________________

父亲老家所在地：______________________________

母亲老家所在地：______________________________

在美国居住时间：______________________________

在 Lawrence 有说中文的机会吗？______________________________

如有，每周大约多长时间：______________________________

对於其他语言(方言)的了解： 请将语言(方言)的名称填写於空白格中，并且说明您对该语言(方言)的听说读写程度

1. 语言: ____________________

听	*说*	*读*	*写*
☐ 差	☐ 差	☐ 差	☐ 差
☐ 一般	☐ 一般	☐ 一般	☐ 一般
☐ 好	☐ 好	☐ 好	☐ 好
☐ 精通	☐ 精通	☐ 精通	☐ 精通

2. 语言: ____________________

听	*说*	*读*	*写*
☐ 差	☐ 差	☐ 差	☐ 差
☐ 一般	☐ 一般	☐ 一般	☐ 一般
☐ 好	☐ 好	☐ 好	☐ 好
☐ 精通	☐ 精通	☐ 精通	☐ 精通

Appendix 4: Language background questionnaire (English version)

Participant #: ________

Language background questionnaire

Name: ____________________ Birthday: _________

Birthplace：____

Where did you attend elementary school? ______________________________

Where did you attend junior high school? ______________________________

Where do/did you attend university? _________________________________

Which province in China was your father born? _________________________

Which province in China was your mother born? _________________________

How long have you lived in America? _________________________________

Do you have opportunity to speak Mandarin in Lawrence? _________________

It yes, how many hours do you speak Mandarin every week? _______________

Knowledge of OTHER dialects of China: Write the name of the dialect in the blank, and indicate your approximate abilities in each of the four areas for each dialect.

1. Dialect: ______________________

Speaking	*Listening*	*Reading*	*Writing*
☐ **Poor**	☐ **Poor**	☐ **Poor**	☐ **Poor**
☐ **Fair**	☐ **Fair**	☐ **Fair**	☐ **Fair**
☐ **Good**	☐ **Good**	☐ **Good**	☐ **Good**
☐ **Near-Native**	☐ **Near-Native**	☐ **Near-Native**	☐**Near-Native**

2. Dialect: ______________________

Speaking	*Listening*	*Reading*	*Writing*
☐ **Poor**	☐ **Poor**	☐ **Poor**	☐ **Poor**
☐ **Fair**	☐ **Fair**	☐ **Fair**	☐ **Fair**
☐ **Good**	☐ **Good**	☐ **Good**	☐ **Good**
☐ **Near-Native**	☐ **Near-Native**	☐ **Near-Native**	☐**Near-Native**